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Effect of processing on starch fractions in different varieties of finger millet

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Abstract

The effect of processing on starch fractions in finger millet (ragi) was studied in a standardized system and convenience mixes. In raw varieties, rapidly available starch (RDS) was 8.3% to 11.1% with slowly digestible starch (SDS) of 26.4% to 35.3%, and total available starch (TAS) 39–53%. The changes in the SDS and TAS were statistically significant. Puffing resulted in an increased RDS and decreased SDS. The changes were more prominent in hill grown varieties as compared to base varieties. Resistant starch (RS) ranged from 0.9% to 1.0% among raw varieties and decreased during puffing. The effect of puffing on gelatinisation of ragi flour was investigated, MR-1 variety showed a single phase transition with gelatinisation temperature of 64 °C, the same was found to be absent in puffed flour reflecting the gelatinisation during puffing. RS formation was influenced by the processing methods, increased during pressure cooking and roasting while dietary fiber increased during cooking and both decreased in all other processing methods. However, its implication in the convenience mix has shown that other ingredients also play a role in the RS content.

Keywords: Finger millet; Starch fractions; Resistant starch; Dietary fiber; Gelatinisation and starch digestibility

1. Introduction

Ragi (finger millet, *Eleusine coracana*) is a nutritious cereal but is less utilized globally. However, in India and Africa it forms a one of the staple cereals for a part of the population. Ragi, being a cereal, contains starch as the major component and its products are slowly digestible. It is rich in dietary fibre and calcium and is used after processing (Malleshi & Hadimani, 1993; Premavalli, Majumdar, Madura, & Bawa, 2003). During processing the starch molecule undergoes several physical changes depending on its type and the processing methods employed (Goni, Garcia-Diz, Manas, & Galixto, 1996). Resistant starch (RS) is also present in ragi; a fraction, which escapes the enzymatic digestion and its fermentation takes place in large intestine, which imparts beneficial effects by preventing several intestinal disorders (Annison & Topping, 1994; Gee, Johnson, & Lind, 1992). RS content and the nature of RS in processed rice have been reported (Mangala, Malleshi, Mahadevamma, & Tharanathan, 1999; Mangala & Tharanathan, 1999) and RS in processed ragi and the structural changes it undergoes on autoclaving has been studied by Mangala, Ramesh, Udayasankar, and Tharanathan (1997, 1999). They reported an increase in RS with repeated autoclaving. The effect of processing treatment on generation of RS in rice and amaranth has been reported by Prachure and Kulkarni (1997). The increase in RS on storage, in ready-to-eat foods has also been reported (Namratha, Urooj, & Prasad, 2000). Though cereals do not differ much in their starch content (70–80%), the nature of starch and in turn its digestibility plays a major role in the rate of absorption. There is evidence that slowly digested and absorbed carbohydrates are favourable in the diet pattern for metabolic disorders such as diabetes, hypertension and obesity (Asp, Johansson, Hallmer, &

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siljestron, 1983; Jenkins, Wolver, & Kalmusky, 1985; Wuresh, 1994). Nutritionally important starch fractions in rice, ragi and jower based Indian foods have been reported by (Sharavathy, Urooj, & Puttaraj (2001), including finger millet roti. In-vitro starch digestibility and nutritionally important starch fractions in one variety each of rice and ragi have been studied, by Arthi, Urooj, & Puttaraj (2003). As described above, limited reports are available on ragi starch and changes during its processing.

Therefore, the present investigation was undertaken to evaluate the varietal effect on nutritionally recognized starch fractions with emphasis on RS in ragi. The effect of puffing ragi on various starch fractions has also been included. The effect of different processing techniques, in control systems as well as processed foods, on RS formation and in vitro digestibility has been studied. The unique approach of comparing the hill grown and base varieties has also been attempted.

2. Materials and methods

2.1. Materials

Ragi (finger millet – *Elusine coracana*) varieties VL-146, VL-149, Vl-204 grown at 5500 ft above sea level were procured from Vivekananda institute, Almora, Uttaranchal, India. Varieties Indaf-5, Indaf-8, Indaf-9, Indaf-11, GPU-28, MR-1, HR-911 grown at 2300 ft above sea level were procured from VC-farm Mandya, Karnataka, India.

All the chemicals used were of analytical grade. Pancreatic α-amylase (Sigma-Aldrich, USA), α-amylase (Sigma-Aldrich, USA), amyloglucosidase (Sigma-Aldrich, USA), pepsin (S.d. fine Chemicals), invertase (Sigma-Aldrich, USA) and autozyme glucose-oxidase/peroxidsae (Crest Bio-systems, Goa, India) were used in the analyses.

2.2. Methods

2.2.1. Ragi processing

Ragi cereal grains procured from hilly and base regions were cleaned well and further used for flour, puffing, germination and malting.

To produce ragi flour: all the varietal samples of native ragi after cleaning were ground in a mill into the flour and passed through 18-mesh-sieve.

For puffed ragi flour: ragi grains were treated with water in the ratio of 1:0.2 ragi:water. After 2 h the moistened ragi was puffed using hot sand at about 230 °C, cleaned well, ground in a mill into flour and passed through 18-mesh-sieve.

2.2.2. Standardized system of processing: raw ragi/ragi flour was used for preparation of various processing as follows

Cooking: Water (200 ml) was kept for boiling, 100 g ragi flour was added to 200 ml boiling water, mixed with a wooden ladle, cooked for 10 min and made into dumplings.

Pressure cooking: Ragi flour (100 g) was thoroughly mixed with water (200 ml) and pressure cooked for 10 min.

Autoclaving: Ragi flour (100 g) was thoroughly mixed with water (200 ml) and autoclaved for 10 min at 121 °C at (15 psi).

Re-autoclaving: Autoclaved sample was cooled to room temperature and re-autoclaved for 10 min at 121 °C (15 psi).

Puffing: Ragi grains (1000 g) were mixed with water (200 ml) and kept for 2 h. Wet grains were puffed at 230 °C using hot sand with continuous stirring.

Roasting: Ragi flour (100 g) was roasted in a deep open pan at a temperature of 160 ± 2 °C for 5 min with a constant stirring.

Baking: Ragi flour (100 g) was mixed with 25 g of hydrogenated fat and kneaded well to make the dough. Then it was moulded like cookies and baked in an oven at a temperature of 180 °C for 20 min.

Frying: Ragi flour (100 g) was thoroughly mixed with 70 ml water to form dough. Dough was kneaded and made into small balls (25 g). These balls were rolled into circle of 3" and 2 mm diameter and fried in cooking oil at 160 ± 2 °C for 3 min.

Toasting (roti): Ragi flour (100 g) was thoroughly mixed with 80 ml water to form dough. Small balls (50 g) were made, rolled flat (5" diameter and 5 mm thickness) and toasted on a hot plate, smeared with cooking oil for 4 min on a medium flame into a roti (chapatti).

Toasting (dosa): Ragi flour (100 g) was thoroughly mixed with 200 ml water to form batter. A cup (40 g) of batter was poured on a hot plate smeared with oil, and toasted for 3–4 min. Dosa had diameter of 4" and thickness of 3 mm.

Germination: Ragi grains (100 g) were soaked in water (250 ml) for 16 h. Excess water was drained off and germinated for 48 h at ambient temperature (18–33 °C). Germinated ragi was ground in a blender.

Malting: Germinated ragi seeds were dried at 50 ± 2 °C in an air oven and ground into flour in a blender.

2.2.3. Ragi based convenience mixes

The mixes have been developed earlier. (Premavalli et al., 2003; Premavalli et al., 2006, Technical Report) The optimized mixes were utilized in the present study.

2.2.4. Isolation of starch

Native finger millet starch: finger millet starch was isolated by water steeping method, according to the procedure of Madhusudan et al. (1995). Finger millet flour was taken and tied in muslin cloth and steeped in water for 30 min. Then the starch was extracted from the flour using water. The extract was collected and kept undisturbed for settling of starch. The supernatant was discarded. The residue was passed through 100 mesh sieve and the water was removed through suction. The solid residue was dried at 50 ± 2 °C for 1 h in an air oven. Starch is blended, packed in polypropylene aluminum foil polyethylene (PFP) pouches.

Puffed starch: The water steeping method could not be adopted for puffed flour since the starch was almost gelatinised during puffing. The puffed flour was defatted using (1:2) chloroform: methanol mixture and dried. Then it was deprotenized. Alkali soluble protein was removed by treating the flour with 5% KCl solution for 1 h and washed with water. Alcohol soluble protein was removed by treating with 80% alcohol. Finally soaked in distilled water to remove water-soluble protein. Then the residue i.e. flour devoid of fat, protein was dried at 50 ± 2 °C for 1 h in an air oven. Starch was blended and packed in polypropylene aluminum foil polyethylene (PFP) pouches.

2.3. Physical and chemical analysis

Raw and puffed ragi flours in standardized systems as well as in the processed products were analysed for the starch fractions. Starch fractions were estimated by the method of Englyst, Kingman, & Cummings (1992). The analysis was carried out under controlled enzymatic hydrolysis with invertase, pancreatic α-amylase and amyloglucosidase at 37 °C in capped tubes followed by measurement of glucose by colorimetric method. Rapidly digestible starch (RDS) was obtained by measuring release of glucose after 20 min of enzymatic incubation while the slowly digestible starch (SDS) was estimated after 100 min of incubation. The total starch was obtained by gelatinisation of the starch for 30 min in boiling water, followed by immediate cooling, treatment with potassium hydroxide at 0 °C, followed by complete enzymatic hydrolysis with amyloglucosidase. Free glucose (FG) was determined by treating the sample with invertase in acetate buffer at 100 °C (water bath) for 30 min. Simultaneous tests were run in a similar manner with standard glucose.

Resistant starch was estimated using method of Goni et al. (1996). One hundred milligrams of sample was dispersed in KCl–HCl buffer, pH 1.5 and incubated at 40 °C with pepsin for 60 min and then tris-maleate buffer was added and again incubated at pH 6.9 with amylase for 16 h. Then the sample was incubated with sodium acetate buffer pH 4.75 and amyloglucosidase for 45 min at 60 °C. The released glucose was measured by GOD-POD diagnostic kit.

In vitro starch digestibility of the ragi flour was determined according to the procedure of Singh, Kherdekar, & Jambunathan (1982) using pancreatic amylase. Sample was dispersed in phosphate buffer, pH 6.8 and incubated with pancreatic amylase at 37 °C for 2 h. After incubation, 3,5 dinitrosalicyclic acid reagent was added and the absorbance measured at 550 nm.

Percent gelatinisation was measured using method of Ibanoglu, Ainsworth, & Hayer (1996). Powdered sample was blended with 100 ml of water and centrifuged at 1500 rpm for 10 min. To 1 ml of supernatant, 1 ml of potassium iodide and iodine mixture were added and the volume was made up to 10 ml. The optical density was measured at 600 nm using a Schimadzo UV-spectrophotometer.

Dietary fiber was estimated using an enzymatic method (Asp et al., 1996). Sample with phosphate buffer pH 6 was heated in the presence of amylase followed by incubation at 40 °C with pepsin at pH 1.5, and with pancreatin at pH 6.8. Subsequently, after adjusting the pH to 4.5, the contents were filtered. The residue was measured as insoluble fiber and the filtrate precipitated with alcohol forming the soluble fraction.

Differential scanning calorimeter (DSC) measurements were performed with a DSC-2010, TA instruments, New castle, USA. Indium was used for calibration of the instrument. One hundred milligrams of sample was mixed with water to make a paste. Ten milligrams of the sample was accurately weighed into aluminum pans and sealed. The pans were heated from 0 °C to 100 °C at the rate of 5 °C/min. An empty pan was used as the reference. Thermal analyses were carried out using software (Universal Analysis ver 2000) provided with the equipment. All reported results are the average of triplicate values.

Water absorption capacity (WAC) and fat absorption capacity (FAC) were determined according to Deshpande, Sathe, Rangnekar, & Salunkhe (1982). For WAC, 5 g sample was transferred into weighed centrifuge tubes in duplicate to which 30 ml of distilled water was added and stirred. After 30 min, 10 ml of distilled water was added. Then the tubes were centrifuged at 1600 rpm for 25 min. The supernatant was discarded and the tubes were weighed. Difference in the two weights of the centrifuged tube gives the water absorbed.

For FAC 1 g sample was transferred in a weighed centrifuge tube to which 25 ml of the groundnut oil was added and stirred. After 20 min, the slurry was centrifuged at 3200 rpm for 25 min and the supernatant was decanted. Then the weight of the tube was noted. The difference in the two weights of the centrifuged tube gives the amount of fat absorbed.

2.4. Statistical analysis

The data obtained was analysed for mean values, standard deviation, ANOVA, correlation and *t*-test by using Microsoft excel 2000 software.

3. Results and discussion

3.1. Varietal differences in behavior of ragi starch fractions

The starch fractions based on digestibility are nutritionally recognized as important because of their impact on physiological functions. The data for starch fractions of 3 hilly and 7 base varieties of ragi and effect of puffing has been tabulated in Table 1. RDS in hilly varieties ranged

Table 1
Starch fractions[a] (%) in raw and puffed ragi flours ($n = 10$)

Varieties	Raw flour				Puffed flour			
	RDS	SDS	TS	RS	RDS	SDS	TS	RS
Hilly region								
VL-146	8.3 ± 0.1	32.3 ± 0.1	44.4 ± 0.3	0.9 ± 0.1	9.7 ± 0.1	21.7 ± 0.2	15.4 ± 0.3	0.7 ± 0.1
VL-149	11.1 ± 0.7	35.3 ± 0.1	50.1 ± 0.2	0.9 ± 0.1	12.2 ± 0.1	24.3 ± 0.3	18.0 ± 0.8	0.64 ± 0.2
VL-204	10.4 ± 0.1	33.7 ± 0.1	47.8 ± 0.2	0.9 ± 0.2	12.9 ± 0.1	24.9 ± 0.2	16.1 ± 0.4	0.7 ± 0.1
Ave ± SD	10.0 ± 1.5	30.6 ± 1.5	47.8 ± 2.8	0.9 ± 0.1	11.6 ± 1.6	20.4 ± 3.3	11.2 ± 1.3	0.7 ± 0.1
Base region								
INDAF-5	9.6 ± 0.1	27.7 ± 0.1	40.0 ± 0.4	0.9 ± 0.2	10.7 ± 0.4	18.7 ± 0.2	15.5 ± 0.4	0.6 ± 0.1
INDAF-8	9.2 ± 0.1	29.4 ± 0.1	41.4 ± 0.1	0.9 ± 0.1	10.1 ± 0.4	19.4 ± 0.3	19.4 ± 0.7	0.7 ± 0.1
INDAF-9	8.4 ± 0.2	26.5 ± 0.2	38.7 ± 0.4	1.0 ± 0.1	10.2 ± 0.3	19.0 ± 0.4	15.1 ± 0.2	0.8 ± 0.3
INDAF-11	8.6 ± 0.2	30.6 ± 0.5	40.9 ± 0.3	0.8 ± 0.1	9.9 ± 0.1	19.8 ± 0.1	17.3 ± 0.1	0.6 ± 0.2
MR-1	9.8 ± 0.2	29.6 ± 0.2	40.7 ± 0.6	1.0 ± 0.3	10.2 ± 0.1	23.2 ± 0.5	17.4 ± 0.1	0.6 ± 0.2
HR-911	9.8 ± 0.1	27.9 ± 0.2	39.7 ± 0.3	0.9 ± 0.1	10.5 ± 0.3	22.1 ± 0.4	19.5 ± 0.3	0.8 ± 0.4
GPU-28	9.5 ± 0.1	28.2 ± 0.2	40.7 ± 0.2	0.9 ± 0.3	10.1 ± 0.1	22.0 ± 0.1	19.7 ± 0.7	0.8 ± 0.2
Ave ± SD	9.3 ± 0.5	28.7 ± 1.7	40.3 ± 1.0	0.9 ± 0.2	10.2 ± 0.3	19.6 ± 1.6	17.0 ± 1.9	0.7 ± 0.3

RDS – rapidly digestible starch, SDS – slowly digestible starch, TS – total starch.
[a] Mean ± SD.

from 8.4% to 11.2% with an average of 10.0 ± 1.4% while in base varieties it ranged from 8.6% to 9.9% with an average of 9.2 ± 0.6%. SDS which is measured after 100 min of incubation varied from 32% to 35% and 26% to 30% in hilly and base varieties respectively, while total starch as measured by enzyme hydrolysis, varied from 44% to 53% and 39% to 41% in hilly and base varieties respectively. Arthi et al. (2003) reported high RDS (29.5%) and (low SDS 3.3%) in one variety of ragi. Resistance starch, a functional fiber which escapes the enzymatic digestion was 0.9% in hilly varieties and ranged from 0.8% to 1% in base varieties. Relatively, hilly varieties had higher RDS, SDS, TS while RS was less as compared to base varieties. Sagum & Arcot (2000) also reported higher SDS and lower RDS in raw rice. However, no reports are available on raw ragi starch fractions. The varietal difference in RS is not considerable and on average 0.9% of RS was present in ragi. According to Mangala et al. (1997, 1999), RS is 0.008% in Indaf variety of ragi. Frei, Siddaraju, & Becker (2003) found 0.1–1.3% RS in rice cultivars while Sagum & Arcot (2000) have reported highest value of 12.9% RS in raw rice. Arthi et al. (2003) reported 4.5% RS in ragi roti.

In puffed ragi flour, the results indicated that RDS increased by 5–18.9% and total available starch decreased drastically which indicated its hydrolysis during puffing. Relatively, the increase in RDS and decrease in SDS was higher in hilly varieties than the base ones, while total starch was slightly lower in hilly varieties. RS, decreased in the range of 19–26% in hilly varieties and 14–31% in the base ones. Mangala et al. (1999) reported an increase of RS by 9–10% in popped ragi. However, the type and conditions of popping were different.

In vitro starch digestibility (SD) is one of the important criteria for determining the status of starch in cereals and to understand the nutritional properties. The SD of ragi varieties both raw and puffed has been depicted in Fig. 1. The SD in raw flour is around 7.2–9.9 mg/g which has

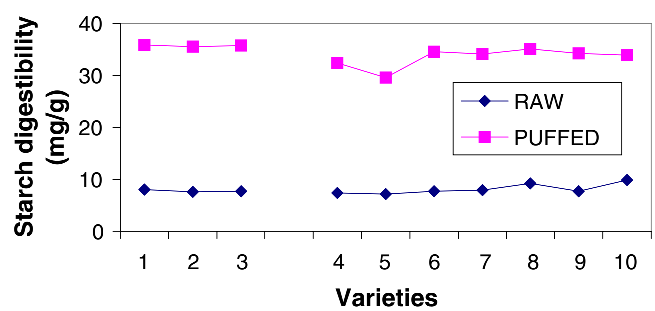

Fig. 1. Starch digestibility of raw and puffed ragi flour.

increased to 29.6–35.8 mg/g in puffed flour (more than four fold increase) which may be due to the starch gelatinization. During puffing gelatinisation has also increased by 70–99% in all these varieties as found by Premavalli, Roopa, & Bawa (2004). In rice, Sagum & Arcot (2000) claimed the improved starch digestibility due to the gelatinization of starch granules and increased viscosity. Increase in RDS with decrease in SDS may also be responsible for better digestibility.

DSC thermogram of raw and puffed flour of variety MR-1 along with its starch has been shown in Fig. 2. From the thermogram, it can be seen that the peak of endotherm starts at 60 °C and reaches 64 °C for ragi flour, where as for puffed flour, no phase transition was found which may be due to the gelatinisation already occurring during puffing. On the other hand, raw starch had the peak at a higher temperature of 72 °C with no phase transition in case of puffed starch. Thus the thermal changes may have an impact on the products where raw ragi flour, puffed flour or starch are used as ingredients. Premavalli et al. (2004) & Mangala et al. (1997) have reported a similar pattern for native ragi flour, starch and retrograded starches.

The analysis of variance amongst the raw ragi varieties for starch fractions revealed that the changes were

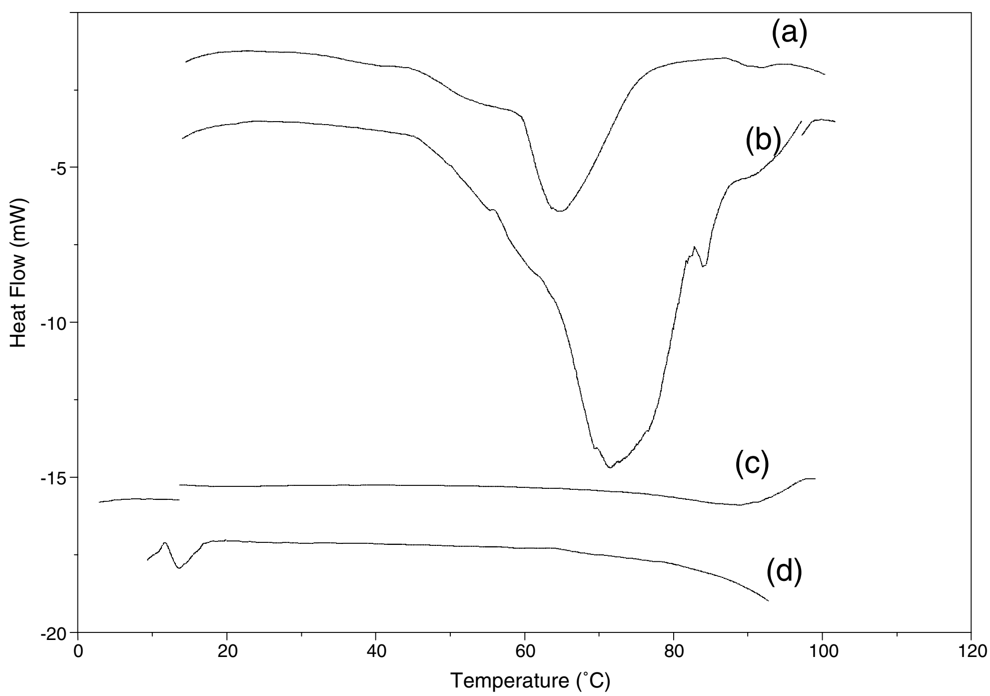

Fig. 2. DSC thermogram of ragi flour and ragi starch: (a) raw flour (b) raw starch (c) puffed flour (d) puffed starch.

Table 2
Water absorption capacity (WAC) and fat absorption capacity (FAC) of raw and puffed flours from different varieties ($n = 10$)

Varieties	WAC[a] (g/g)		FAC[a] (g/g)	
	Raw	Puffed	Raw	Puffed
Hilly region				
Vl-146	1.6 ± 0.1	5.0 ± 0.1	1.1 ± 0.1	1.9 ± 0.1
VL-149	1.5 ± 0.1	4.9 ± 0.3	1.0 ± 0.2	1.6 ± 0.3
Vl-204	1.5 ± 0.2	4.9 ± 0.2	1.2 ± 0.2	1.8 ± 0.4
Ave ± SD	1.5 ± 0.1	4.9 ± 0.2	1.1 ± 0.2	1.8 ± 0.2
Base region				
INDAF-5	1.4 ± 0.8	4.1 ± 0.1	1.1 ± 0.3	1.3 ± 0.2
INDAF-8	1.4 ± 0.6	4.1 ± 0.4	1.0 ± 0.3	1.5 ± 0.2
INDAF-9	1.4 ± 0.1	3.5 ± 0.5	1.1 ± 0.1	1.6 ± 0.2
INDAF-11	1.3 ± 0.2	4.1 ± 0.1	0.9 ± 0.1	1.6 ± 0.1
MR-1	1.5 ± 0.1	4.2 ± 0.3	0.9 ± 0.3	1.3 ± 0.1
HR-911	1.3 ± 0.3	4.0 ± 0.1	1.1 ± 0.2	1.3 ± 0.1
GPU-28	1.2 ± 0.1	4.2 ± 0.2	1.2 ± 0.2	1.3 ± 0.1
Ave ± SD	1.3 ± 0.1	4.0 ± 0.3	1.0 ± 0.2	1.4 ± 0.2

WAC – water absorption capacity, FAC – fat absorption capacity.
[a] Mean ± SD.

Table 3
Students '*t*'-test of starch fractions-raw and puffed ragi flour

	RDS	SDS	TS	RS
Between raw and puffed varieties				
(a) Hilly	0.031	0.0028	0.0005	12.1[*]
(b) Base	0.002	1.08	1.06	5.6[*]
(c) Total	0.0002	2.85[*]	9[*]	7.53[*]
Between varieties				
(a) Raw (hilly n puffed)	0.71	4.57[*]	4.22[*]	−1.85
(b) Puffed (hilly n puffed)	1.4	0.39	−1.15	−0.72

RDS – rapidly digestible starch, SDS – slowly digestible starch, TS – total starch, RS – resistant starch.
[*] Significant at 5% level.

non-significant ($p > 0.05$). However, between the hilly and base varieties, the changes in SDS, TS were significant ($p < 0.05$) while changes in RDS were non significant as per the students '*t*' test (Table 3).

The formation of RS during processing and its effect on humans is of recent interest. In this study, in order to understand the relationship amongst the fractions, correlation coefficient between RS and RDS, SDS, TS were calculated (Table 4). In both raw and puffed samples RS was negatively correlated to RDS and SDS, TS fractions did not correlate well. When hilly and base varieties were considered, only RS and RDS were highly correlated in raw, base varieties. These results gave an idea that RS formation may be more related with the RDS fraction. The significance of the changes in RS and other fractions was calculated by students '*t*' test. The changes were significant at 5% level between RS and SDS, TS in raw samples and with SDS in puffed samples. Further, in base varieties the changes are significant ($p < 0.05$).

Water and fat absorption of cereal flours is an important functional factor during development of processed foods and is also governed by flour starch. The varietal changes with reference to water holding capacity (WAC) and fat absorption capacity (FAC) have been given in Table 2. The WAC of hilly varieties was higher than that of the base varieties. However, the FAC remained the same. The puffing of ragi increased the WAC by nearly three and half times and FAC by nearly one and half times as compared to the raw samples. Puffing increased gelatinisation of flour

Table 4
Correlation and test of significance between resistant starch (RS) and starch fractions

	Fractions	Raw (total)	Puffed (total)	Raw (hilly)	Puffed (hilly)	Raw (base)	Puffed (base)
Correlation	RDS	−0.105	−0.27	0.56	−0.63	−0.007	−0.370
	SDS	−0.626	−0.39	0.80	−0.60	−0.705	−0.397
	TS	−0.443	0.44	0.68	−0.99	0.597	0.531
‘*t*’-test	RDS	1.10	1.57	0.004	0.003	8.92*	1.61
	SDS	8.43*	6.84	0.0003	0.0009	7.33*	5.28*
	TS	3.39*	1.26	0.0006	0.0011	2.00*	1.78

RDS – rapidly digestible starch, SDS – slowly digestible starch, TS – total starch, RS – resistant starch.
* Significant at 5% level.

by 70–99% (Premavalli et al., 2004) and probably this may be the reason for easy imbibation of water and resultant increased WAC.

3.2. Standardized system of processing

In order to understand the behavior of starch during processing, a standardized system of processing was adopted using only ragi flour (MR-1) and other ingredients. The processing effect on Starch fractions in standardized systems has been presented in Table 5. RDS level for all the 12 processing methods ranged from 6.0% to 23.5% as against 9.8% for native ragi flour. Baking, frying and shallow frying reduced RDS while roasting and pressure cooking enhanced the formation of RDS to about 23% followed by cooking, autoclaving 16%, puffing and malting. Germination slightly increased RDS as compared to raw ragi flour. Repeated autoclaving decreased RDS. However, SDS decreased in the case of all the processing methods ranging from 5% to 24% as against 29.6% in native ragi flour, however the extent of decrease was dependent on the type of processing. Baking, frying, germination and malting brought down the SDS to 4–8% while in other methods 14–24% decrease was observed. Sagum & Arcot (2000) have reported increased RDS and decreased SDS during boiling and pressure cooking of rice varieties. RS increased only during pressure cooking and roasting while in all other processes RS decreased. Repeated autoclaving further decreased the RS. However, Mangala et al. (1999) showed that repeated autoclaving increased the formation of RS. In addition to that, all the processes-popping, roller drying, extrusion, flaking, parboiling, malting increased the RS formation both in rice and ragi flours. In contrary Prachure & Kulkarni (1997) reported a decrease in RS during roasting, pressure cooking, frying and cooking methods. In rice, Sagum & Arcot (2000) have also reported a reduction in RS during boiling. In a standardized system of processing, the changes in SD and percent gelatinisation during processing have been represented in Fig. 3. SD was increased to about 35–40% during cooking, autoclaving and puffing followed by repeated autoclaving, pressure cooking and germination (25–30%). In all other processing methods, digestibility was found to be 10–12%. Parallely, percent gelatinisation changes were found to be the highest during puffing (97%), pressure cooking (89.2%), autoclaving (65.4%), cooking (56.3%) and repeated autoclaving (65.4%). In all other methods it was less than 25%. Probably, the increase in SD in water related methods may be due to the gelatinisation of the flours during processing. The results for the effect of processing on dietary fiber fractions in standardized system have been tabulated in Table 6. Dietary fiber ranged from 9.7% to 15.7% for various processing methods. Cooking methods resulted in relatively higher dietary fiber content. Relatively, insoluble fiber contributed to 87–90% with 10–13% of soluble fiber fraction.

Table 5
Processing effect on starch fractions (%) and resistant starch (%) in standardized system

Processing	RDS (%)	SDS (%)	RS (%)
Native flour	9.8	29.6	1.0
Cooking	16.0	17.1	0.7
Pressure cooking	23.5	18.5	1.7
Autoclaving	16.3	23.4	0.6
Re-autoclaving	14.3	23.0	0.4
Puffing	10.2	23.2	0.6
Roasting	23.2	14.0	3.1
Baking	1.8	5.4	0.5
Frying	2.8	8.4	0.3
Germination	9.9	5.5	0.6
Malting	10.5	5.0	0.7
Toasting (roti)	8.9	22.9	0.4
Toasting (dosa)	6.0	19.6	0.4

RDS – rapidly digestible starch, SDS – slowly digestible starch.

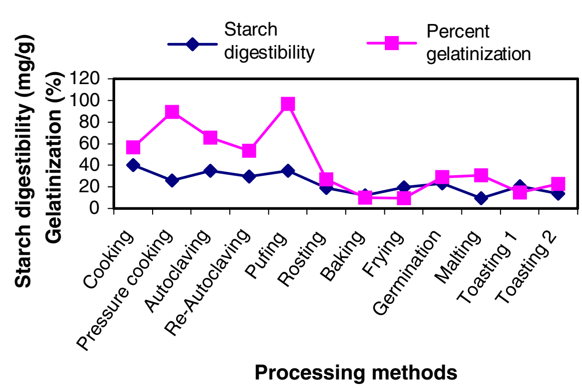

Fig. 3. Starch digestibility and gelatinisation in standardized system of processing.

Table 6
Effect of processing on dietary fiber fractions[a] (%) in standardized system ($n = 10$)

Processing	Insoluble fiber	Soluble fiber	Total fiber
Native flour	18.1 ± 0.4	0.7 ± 0.9	19.8 ± 0.5
Cooking	13.0 ± 0.2	1.9 ± 0.2	14.9 ± 0.2
Pressure cooking	14.0 ± 0.2	1.6 ± 0.1	15.7 ± 0.5
Autoclaving	13.9 ± 0.2	1.5 ± 0.1	15.4 ± 0.1
Re-autoclaving	12.8 ± 0.1	1.9 ± 0.1	14.7 ± 0.2
Puffing	19.6 ± 0.2	0.8 ± 0.2	20.3 ± 0.2
Roasting	13.1 ± 0.4	1.6 ± 0.2	14.7 ± 0.1
Baking	8.6 ± 0.2	1.2 ± 0.3	9.7 ± 0.4
Frying	11.1 ± 0.9	1.1 ± 0.3	12.2 ± 1.0
Germination	8.9 ± 0.3	1.8 ± 0.1	10.7 ± 0.4
Malting	8.8 ± 0.1	3.3 ± 0.1	12.0 ± 0.4
Toasting (Roti)	12.6 ± 0.2	1.1 ± 0.3	13.6 ± 0.3
Toasting (Dosa)	9.8 ± 0.1	1.3 ± 0.1	11.1 ± 0.2

[a] Mean ± SD.

In native ragi flour, the insoluble fiber of MR-1 variety used in these studies was 18.1% with a soluble fiber of 0.7% Premavalli et al. (2004).

Sharavathy et al. (2001) have reported as the RS in ready to eat cereal based foods. Amongst these 11.2% RS has been reported in ragi roti. The storage changes in RS in processed ready to eat foods have been reported by Namratha et al. (2000) and a significant increase in RS during storage was observed. However, RS in convenience mixes has been reported in the present study. Ultimately, the relevance of processing methods does matter in the development of processed foods. The SD and RS contents in millet based convenience mixes have been presented in Table 7. The digestibility was found to be higher in sweetened millet mix, spiced millet mix, beverage mix, where puffed ragi flour was the major ingredient. In the other 8 mixes, it was 9.3–40.3 mg/g where raw ragi flour was one of the major ingredients. However, in kheer mix, beverage mix, 24.7 mg/g SD, on the higher side, may be attributed to the use of millet starch as an ingredient in place of flour. Thus it depends on the ingredient form used in the mixes.

Table 7
Resistant starch (RS) content and in-vitro starch digestibility (SD) in ragi based convenience mixes ($n = 12$)

Convenience ragi mixes	RS (%)*	SD (mg/g)*
Functional cookie mix	0.6 ± 0.1	10.2 ± 0.2
Sweet cookie mix	0.3 ± 0.3	9.3 ± 0.3
Sweetened millet mix	2.4 ± 0.1	32.9 ± 0.4
Spiced millet mix	1.1 ± 0.1	38.1 ± 0.8
Millet chapati mix	1.0 ± 0.2	12.1 ± 0.4
Millet roti mix	0.6 ± 0.1	10.9 ± 0.2
Millet dosa mix	0.9 ± 0.1	14.7 ± 0.1
Millet pakoda mix	0.6 ± 0.7	13.8 ± 0.1
Millet nippatu mix	0.8 ± 0.1	10.9 ± 0.7
Millet beverage mix	0.6 ± 0.1	40.5 ± 0.5
Millet kheer mix	0.2 ± 0.2	24.7 ± 0.5
Millet halbai mix	0.7 ± 0.3	11.1 ± 0.6

* Mean ± SD.

The RS, content, a functional fiber ranged from 0.2% to 2.4% in mixes, however it was relatively higher in cold water re-constitutable convenience mixes.

4. Conclusion

The starch fractions from 3 hilly and 8 base varieties of ragi (finger millet) were investigated. Hilly varieties had higher RDS, SDS, and TAS and were low in RS as compared to their base counterparts. During puffing of ragi, RDS increased with decrease in SDS, which was more prominent in hilly varieties. However, decrease in RS was higher in the case of base varieties. Puffing increased gelatinisation, there improving the starch digestibility. DSC thermogram showed that gelatinisation peak occurring at 60 °C for raw flour but only crystalline melting occurred in the use of puffed ragi. The increase in gelatinisation in puffed flour has been confirmed by DSC thermogram with no gelatinisation peak in the case of puffed samples. Gelatinisation temperature values were higher for starch as compared to flour. According to statistical analyses, the changes were significantly ($p < 0.05$) different between the hilly and base varieties. The changes in RS with reference to other fractions were statistically significant and RS formation may be related more to RDS fraction.

In order to have more insight into the behavior of starch during several common processing methods, standardized system studies were also conducted. Amongst starch fractions, RDS increased in case of all the processing methods except for baking, frying and toasting with oil, while SDS decreased in all the methods indicating the improved digestibility during processing. RS, a functional fiber increased during pressure-cooking and roasting while dietary fiber increased during cooking and both decreased in use of all the other methods of processing. However, their implications in the convenience products have shown that other ingredients also play a role in the RS content. It is clearly shown that in puffed flour, RS decreased while in sweetened and spiced millet mixes where puffed flour was the major ingredient RS was high. The whole study gave a very pragmatic view of the properties of ragi starch, agronomical implications, effect of processing and a systematic study with a first of its kind, report on hilly varieties as well as effect of puffing.

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